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Historic rammed earth structures in Spain, construction techniques and a preliminary classification

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Conservation and repair of historic rammed earth sites should only be undertaken if there is a good understanding of the consequences of any intervention technique. Until recently there has been little interest in the characterisation of historic rammed earth construction, yet it is only with this understanding that successful conservation strategies can be adopted.

A survey of around 60 historic rammed earth sites in Spain constructed between 967AD and 1837AD has recently been undertaken. While all the sites are built primarily in rammed earth, the construction techniques and state of repair vary greatly. The high density of historic rammed earth structures in the Iberian peninsula is likely due to the Muslim presence there from the 8th century onwards. Initial expansion, a period of civil war and eventual defeat by Christians led to the construction of a large number of fortifications, many constructed in rammed earth. A famous example is the Alhambra at Granada, but there are hundreds of smaller sites throughout Spain. By the end of the 15th century Christians had replaced Muslims through most of Spain, but rammed earth continued to be used in both vernacular and monumental architecture.

Examples of historic construction techniques are presented and common features of historic rammed earth construction are identified. A classification is outlined and a clear development of the rammed earth technique is observed.

Keywords; Rammed earth, historic construction, building techniques, failure

Introduction

Rammed earth is a simple construction technique based on compacting earth between formwork to make a homogeneous mass wall. It has recently become popular in Australia, the USA and other parts of the world because it is recognised as a sustainable building material (Easton 2007). Few rammed earth practitioners however realise the full extent of historic rammed earth construction and the varied techniques used in the past. A better understanding of historic rammed earth construction techniques would undoubtedly lead to improved modern rammed earth construction, and better conservation of historic sites. This paper presents one of the first overviews rammed earth construction during medieval and later

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historic periods. It seeks to identify characteristics by which different types of rammed earth construction can be recognised, in order to provide a framework by which different rammed earth buildings can be compared.

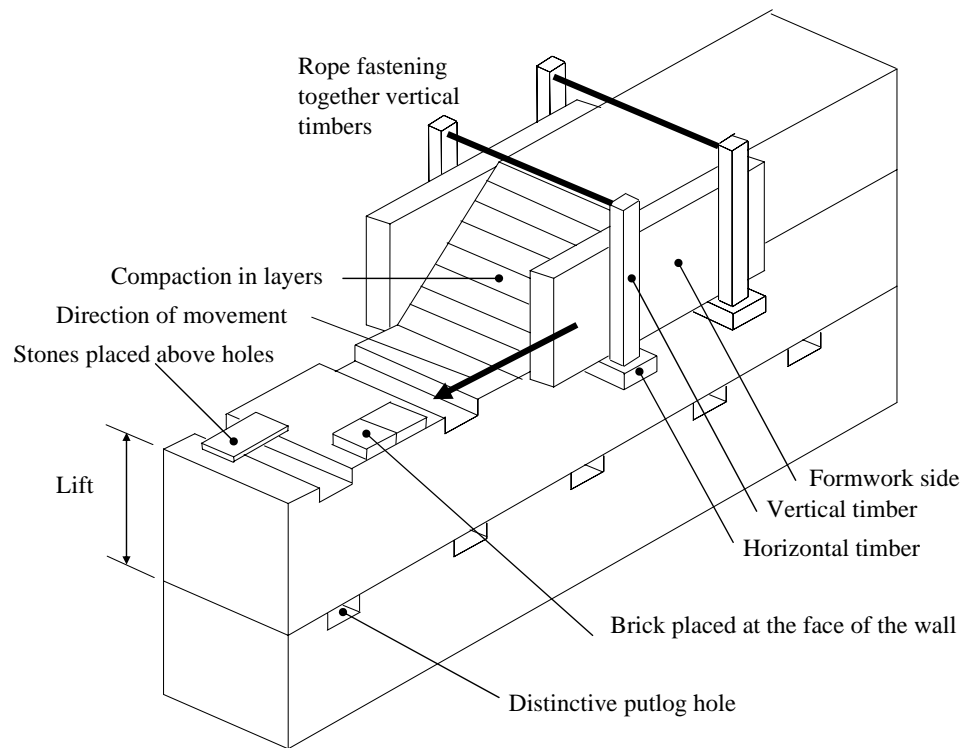


Figure 1 Features of typical historic rammed earth construction

To construct a rammed earth wall, a formwork box is constructed using two parallel timber sides, supported on two or more horizontal timbers. Vertical timbers are then placed through holes in the ends of the horizontal timbers thereby restraining the formwork. These vertical timbers are connected at the top using rope, forming an open box. Soil is taken from the ground and if necessary sieved to remove larger particles. Additives such as straw or lime may be mixed into the soil, which is then dropped into the formwork in layers, usually around 150mm high. The layer is then compacted using a heavy rammer. Upon compaction of one layer, another layer of earth is placed in the formwork and the process repeated until the formwork is full. The formwork is then removed and placed on the next set of horizontal timbers where the process is repeated. Once the formwork has been moved on, the horizontal timbers are removed from the wall leaving characteristic holes usually called *putlog* (*mechinales* in Spanish) holes by architectural historians. Upon completion of one horizontal level the formwork is moved vertically, the mass of standing wall being known as a *lift*. A

rammed earth wall can thus be constructed using very little manpower and crucially without recourse to temporary works such as external scaffolding.

Study area

The data presented here are compiled from literary sources, together with field data gathered by the authors. Spain was chosen for its high density of well researched rammed earth sites and excellent transport links, allowing access to a large number of structures over a short period of time. The sites studied were constructed between the 10th and the 19th century, and the use of rammed earth changed markedly over this time period, allowing observation of a wide variety of structures including isolated fortifications, city walls, and vernacular architecture. Figure 2 shows the locations of the sites visited, each mark indicating a site, or number of sites within a town or city,



Figure 2 Map of sites visited

Characterisation

The characterisation of typologies of rammed earth is important if we are to understand the behaviour of a rammed earth wall from visual inspection. Only with this knowledge is it possible to anticipate for example the erosion which may occur to a wall or to predict the structural behaviour of a building. However, typological descriptions of rammed earth have ‘raised little interest when compared to ornamental and spatial studies’ and only recently have any attempts been made to classify historic rammed earth construction. Graciani García and

Tabales Rodríguez (2003) identify the following variables which they use to distinguish between various rammed earth types in the Seville area of southern Spain.

- Composition of the wall; identifying plain rammed earth, horizontal brick layers between each *lift*, and walls of mixed composition, where some *lifts* are separated by a brick layer, and others are continuous.
- Dominant aggregate used; distinguishing between predominantly gravel mixtures and those which contain ceramic fragments.
- Height of the *lift*; two dimensions were observed in Seville, that of short (0.80m), and high (0.85m and 0.95m).

Investigations carried out by the author's have led to the conclusions that the dominant aggregate type is dependent on the geology local to the site, and that rammed earth is only used as a construction material if the surrounding geology is sufficient to produce a satisfactory rammed earth mix. The height of the lifts is considered to be determined by local carpentry traditions, and while the size of the formwork may change over time, it is also likely to vary spatially, and thus classification using this method is difficult without a large sample set. A classification using the following characteristics is thus proposed.

Formwork

It is the formwork which distinguishes rammed earth from other variants of earthen construction such as cob or adobe. Many formwork types have been suggested over time and in different parts of the world, with the formwork evolving to become more efficient, or being forgotten and rediscovered some years later (for example Cointeraux 1791). Formwork is usually made from planks of timber, fixed together and placed to form a box within which the earth is rammed. Formwork can either be supported by horizontal timbers passing through the wall or supported using an external scaffold. Where the formwork is supported on horizontal timbers, the characteristic *putlog* holes are formed, a feature of some historic rammed earth. It may be possible to determine the weight of the formwork by observing the size and spacing of the horizontal timbers. Timbers around 70mm wide by 25mm high appear to be used in the majority of rammed earth construction (see Figure 4) but a small number of sites used horizontal timbers 100mm square, indicating that very heavy formwork was used (Figure 4 example 5). Where no *putlog* holes are present it is likely that the formwork was supported externally using scaffolding (Figure 4, example 3).

Mix design

Three distinct styles for the filling and ramming of the formwork may be recognised. Each uses a different mix design and ramming technique, and produces distinctive external appearances. However when a face is rendered or badly eroded the techniques are more difficult to identify. Gallego Roca and Valverde Espinosa (1993) identify two different types of mix design, that of *Calicaraedo* and of ‘royal’ rammed earth (*Tapial Real* in Spanish). A further ‘plain’ rammed earth has been observed.

Calicaraedo rammed earth

This method uses a lime and earth mixture (*careado*) which is spread by shovel against the formwork, the interior is then filled with a sand – gravel mixture which is then compacted. When the formwork is removed, a lime rich wall face is presented, with the lime fused to the fill behind (Bazzana 1993; Gallego Roca and Valverde Espinosa 1993). The wall then has two distinct regions; a core of rammed earth which acts to give structural strength and mass, but is vulnerable to erosion, and an outer face which protects the wall from the weather (Valverde Espinosa et al. 1993; Arango Gonzalez 1999). Sometimes the external face is rendered following initial construction, and it is this render which is reapplied periodically to prevent moisture ingress (Figure 4, examples 1, 4, 5 and 9) and allows patterns to be inscribed into the face of the wall. Observation of a number of sites suggests that once the lime rich exterior is removed, the wall core quickly erodes.

Royal rammed earth (*Tapial Real*)

Also known as Arab-concrete, ‘royal’ rammed earth consists of a lime and earth mixture compacted in layers, where the lime:earth ratio is approximately 1:3 (Figure 4, example 7). Walls constructed using this technique are found in the 8th century Alcazaba Cadima in Granada (Arango Gonzalez 1999). Royal rammed earth does not require rendering due to the high lime content and this makes structures both stronger and more expensive than other types of rammed earth, hence the name ‘royal’. In practice, ‘royal’ rammed earth is difficult to distinguish from plain rammed earth, except in colour and through mineralogical testing of samples.

Plain rammed earth

Similar to the ‘royal’ rammed earth mix, but with a significantly lower lime content. This technique is closest to modern ‘unstabilised’ rammed earth such as found at the Eden Project in Cornwall, UK. A common feature of this type of rammed earth is horizontal banding visible at the surface of the wall marking either the compaction layers or indicating the timbers used for the formwork (Figure 4, examples 2 and 8).

Lift bond

When one horizontal layer of rammed earth is complete, the formwork is dismantled, moved vertically and another horizontal layer begun. Because construction progresses horizontally, there may be a delay in the vertical movement of the formwork and as a result the bond between each *lift* may be weaker than the bond between each compaction layer within the formwork.

Almost all of the construction typologies observed make use of a flat stone or brick placed above the horizontal timber used to support the formwork (Figure 1). This bridging device facilitates compaction of the rammed earth above the horizontal timber and allows the timber to be removed and reused on completion of that formwork box. Usually these stones are spread through the full thickness of the wall, but are often not visible at the face of the wall.

The majority of typologies identified construct a new layer directly on the previous one. The only indication of a *lift* is the line of *putlog* holes visible in the wall. However a proportion of the sites visited do have some material placed through the full thickness of the wall, between each lift. Layers of other material placed between the lifts are known in Spanish as *males*. Rammed earth constructed with *males* is termed ‘*chained*’ by Graciani García and Tabales Rodríguez (2003). The majority of the *males* are made using brick, but some in Seville dating from the first half of the 13th century are constructed in stone (Figure 4, example 5), and in Cordoba parts of the city walls have a lime *male* between the joints (Figure 4, example 4). Brick *males* were introduced in the second half of the 12th century, (Graciani García and Tabales Rodríguez 2003). The *male* can be between one and three bricks thick, and the bricks are usually only present at the surface of the wall. The *putlog* hole is usually below the level of the *male*, indicating that the male was the first, rather than the last, layer laid within a *lift*. All the structures where a male is present are constructed using the *calicaraedo* mix.

The mixed fabric technique outlined in Graciani García and Tabales Rodríguez (2003) was observed at a small proportion of sites. A number of lifts are constructed with no material between the lifts, then a brick layer is introduced. This usually occurs where rammed earth is used as an infill within a brickwork superstructure (Figure 4, example 8).

While the *males* may have been introduced to strengthen the bond between lifts, Langenbach (2004) argues that *males* are provided for seismic resistance, and notes that horizontal introductions into the walls of buildings are not unique to rammed earth, or even earthen architecture. Hurd (2006) argues that vegetable matter placed as a ‘mattress’ between each third lift, observed in Armenia and in India is placed as seismic protection. The horizontal members are designed to act as weak layers, forcing diagonal shear cracks to propagate horizontally and so preventing collapse of the building.

Design

With the increasing availability, but high cost, of fired brick around the 16th century there are examples of rammed earth walls being constructed and faced in half bricks, thus giving the impression of an expensive brick structure, the reality being a rammed earth wall acting structurally behind (Figure 4, example 6). By the 19th century rammed earth appears to have been used more as an infill, much as modern blockwork, between a brick superstructure (Figure 4, examples 7-9). Also observed was a technique known as *lunetos* (literally, ‘moons’) where lime was placed in a half moon within the ends of the formwork boxes (Figure 4, example 10.). This technique increases the strength and durability of the corners of the rammed earth box. With the advent of artillery, many of the rammed earth walls which were still in military use were faced with masonry to protect against bombardment.

Conclusions

A large number of different structures have been studied, and a number of different typologies identified. These typologies are based on the type of formwork used, the mix design, and the type of joint used between each lift. Figure 3 shows the characteristics observed, and the initial construction dates of structures with those characteristics and Figure 4 presents example structures typifying the characteristics observed. It can be seen from Figure 3 that there is a clear development of the rammed earth technique in Iberia from the 10th to the 19th century. Within this development however, there is room for spatial and economic variation, with the mix design and formwork size changing to suit local geology and traditions. For example the choice between *calicaraedo*, royal or plain rammed earth would be based on

geological and economic considerations. The visual appearance of a structure becomes increasingly important in monumental buildings over time, and the use of brick slowly increases, for ornamental and prestige purposes. Where a rammed earth structure is purely defensive, it is clad in masonry from the 15th century onwards, but the use of rammed earth in vernacular structures such as barns continues into the 19th century.

Buildings constructed during the Muslim expansion and civil war periods were built in rammed earth for their speed of construction and structural integrity. Internally supported formwork, leaving small putlog holes was used and where lime was available a *careado* mixture and render was used (Figure 4, example 1). Where lime was not available, a plain rammed earth mixture was used (Figure 4, example 2). For city walls, too thick for internally supported formwork, external scaffolding was used, and no putlog holes are left in the wall (Figure 4, example 3). First lime (Figure 4, example 4) then brick (Figure 4, example 5) *males* are introduced into rammed earth walls. Brick was used in conjunction with rammed earth in various forms, such as facing of rammed earth walls to appear as brick (Figure 4, example 6), and as brick quoins with a rammed earth infill (Figure 4, examples 7 and 8). Following the reconquest of Iberia by Christians, Muslim builders were employed by the Christians, and these Muslims continued to use rammed earth as a construction technique. The advent of artillery in the 15th century led to the cladding of rammed earth structures in masonry, and there may be many rammed earth walls currently 'hidden' beneath masonry walls. Rammed earth continued as a vernacular building technique throughout Spain, Portugal and France until its 'rediscovery' by Francois Cointeraux in 1793. Rammed earth continued to be used in conjunction with brick as an ornamental feature (Figure 4, example 9) or using as a quick cheap construction material using *lunetos* (Figure 4, example 10).

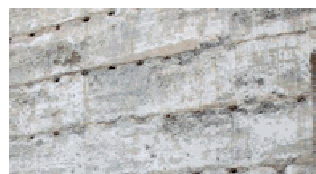
This paper has shown that a clear development of the rammed earth technique can be quantified and is observed in the relatively small geographical area that has been studied. It is hoped that this framework can be extended to cover other parts of the world, and thus comparisons made between geographically or historically distant types of rammed earth. It has been argued that some aspects of rammed earth development are dependent on local human factors (for example formwork height and wall thickness), others (mix design and lime content) are dependent on local geology, while many 'design' features, and the placing of a *male* layer appear to develop over time.

Typology (from Figure 4)	Form work		Mix	Male			Design				Initial construction dates									
	Internal	External	Calicaraedo Royal Plain	None Lime Brick	Plain Brick faced Brick columns Lunetos						1000	1100	1200	1300	1400	1500	1600	1700	1800	
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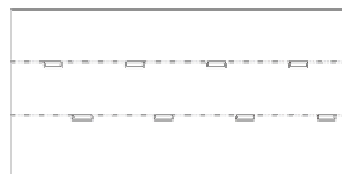
Figure 3 Typological changes to rammed earth over time, examples are shown in Figure 4

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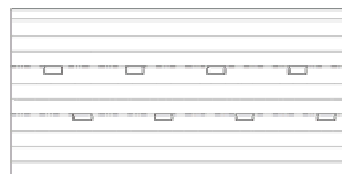
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Castillo de Baños de la Encina, Andalucia. 967



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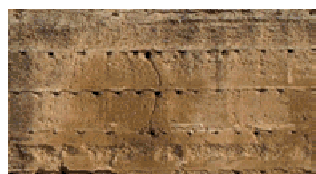
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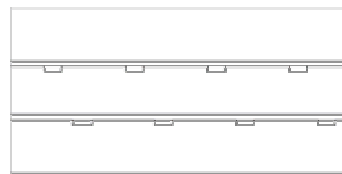
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Seville city walls, Calle Macarena, Seville. 1107



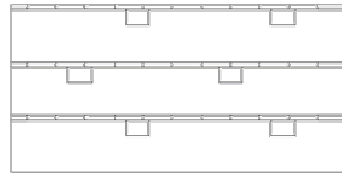
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Cordoba city walls, Avenida del Corregidor, Cordoba. 1369



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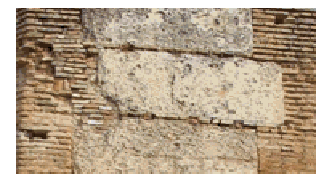
Alcazar Real, Alcala de Guidaira, Seville, 1350



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Ambel Preceptory, Ambel, Aragon. 1567



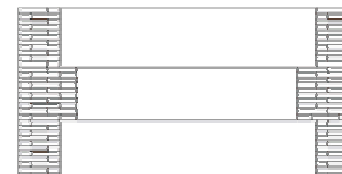
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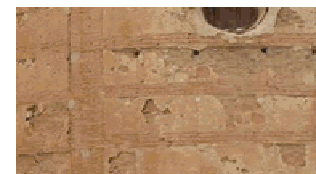
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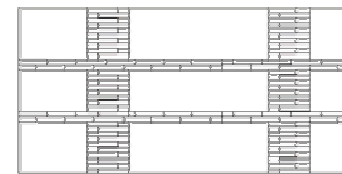
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Castillo Salobrena, Salobrena, Andalucia. 1408



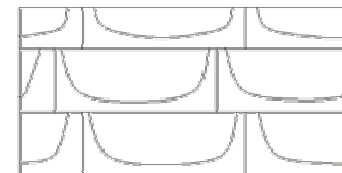
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Villafeliche Chapel. Aragon. 19th century



10



Barn, Villafeliche, Aragon. 19th century

Figure 4 Rammed earth typologies in Spain